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El Niño Southern Oscillation (ENSO) and annual malaria incidence in Southern Africa

Musawenkosi L.H. Mabaso [a,b,*], Immo Kleinschmidt [a], Brian Sharp [a], Thomas Smith [b]

[a] *Malaria Research Lead Programme, Medical Research Council, South Africa, P.O. Box 70380, Overport 4067, South Africa*

[b] *Department of Public Health and Epidemiology, Swiss Tropical Institute, Socinstrasse 57, P.O. Box CH-4002, Basel, Switzerland*

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Summary We evaluated the association between annual malaria incidence and El Niño Southern Oscillation (ENSO) as measured by the Southern Oscillation Index (SOI) in five countries in Southern Africa from 1988 to 1999. Below normal incidence of malaria synchronised with a negative SOI (El Niño) and above normal incidence with a positive SOI (La Niña), which lead to dry and wet weather conditions, respectively. In most countries there was a positive relationship between SOI and annual malaria incidence, especially where *Anopheles arabiensis* is a major vector. This mosquito breeds in temporary rain pools and is highly sensitive to fluctuations in weather conditions. South Africa and Swaziland have the most reliable data and showed the strongest associations, but the picture there may also be compounded by the moderating effect of other oscillatory systems in the Indian Ocean. The impact of ENSO also varies over time within countries, depending on existing malaria control efforts and response capacity. There remains a need for quantitative studies that at the same time consider both ENSO-driven climate anomalies and non-ENSO factors influencing epidemic risk potential to assess their relative importance in order to provide an empirical basis for malaria epidemic forecasting models.

1. Introduction

The El Niño Southern Oscillation (ENSO) phenomenon refers to the cyclic warming and cooling of the equatorial Pacific Ocean coupled with changes in the atmospheric pressure across the Pacific. This is the most important climatic cycle contributing to worldwide interannual variability in climate and the likelihood of climatic anomalies. The two extremes of ENSO are El Niño (a warm event) and La Niña (a cold event), which create rainfall and temperature fluctuations. Their impact varies across the regions of the globe and can result in drought in some areas and flooding in others (Bouma et al., 1997a; Kovats, 2000; Kovats et al., 2003; Nicholls, 1993).

* Corresponding author. Tel.: +27 31 203 4700; fax: +27 31 203 4704.
E-mail address: mabasom@mrc.ac.za (M.L.H. Mabaso).

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There is strong evidence that ENSO is associated with heightened risk of malaria in regions of the world where climate is linked to the ENSO cycle (Kovats, 2000; Kovats et al., 2003). These include, among others, countries in South Asia and Latin America (Bouma and Dye, 1997; Bouma and van der Kaay, 1994, 1996; Bouma et al., 1997b; Gagnon et al., 2002; Poveda et al., 2001). In Africa, this is supported mainly by studies carried out in the East African highlands of Uganda (Kilian et al., 1999; Lindblade et al., 1999), Tanzania (Lindsay et al., 2000; Wort et al., 2004) and Rwanda (Loevinsohn, 1994). ENSO also has a strong influence on interannual climate variability in Southern Africa (Kovats, 2000; Kovats et al., 2003; Nicholls, 1993; Richard et al., 2000, 2001) and is the main climatic phenomenon responsible for some malaria epidemics in the region (Le Sueur et al., 1996; Southern African Malaria Control Programme, 2003). However, quantitative analysis of the link between ENSO-related climate anomalies and malaria incidence is limited to a recent study in Botswana (Thomson et al., 2005).

In Southern Africa the challenge is that, owing to a long history of malaria control, baseline endemicity has been substantially reduced and in most places immunity is low (Mabaso et al., 2004). Under such conditions, seasonal transmission results in high morbidity and mortality if not prevented or contained (Southern African Malaria Control Programme, 2003). Consequently, disruption or failure of existing control activities induces epidemics (Craig et al., 2004a; Mabaso et al., 2004). Thus, climate is not the only factor that has an impact on the epidemic potential and the question is how sensitive malaria transmission is to the impact of ENSO and whether its effects can be separated from other factors influencing epidemic risk in the region. Interannual fluctuations in malaria are driven mainly by climate variability; the extent of these fluctuations is indicative of areas prone to epidemics (Craig et al., 2004b; Southern African Malaria Control Programme, 2003; Thomson et al., 2005).

In this study, we evaluated the association between interannual variability in malaria incidence and ENSO from 1989 to 1999 in five countries across Southern Africa in order to determine its relative impact given the existing malaria situation.

2. Materials and methods

2.1. Study area

Countries included in the study were Botswana, South Africa, Swaziland, Zambia and Zimbabwe based on the availability of malaria data. In these countries there are many areas with intense seasonal transmission as well as epidemic-prone and malaria-free areas. In Southern Africa, the total population is approximately 145 million people, of whom approximately 92 million live in malarious areas, with approximately 21 million cases and 300 000 deaths reported annually (Southern African Malaria Control Programme, 2003). The risk of malaria varies considerably both spatially and temporally. Rainfall and temperature are the main limiting climatic factors for transmission of malaria in this region (Craig et al., 1999; Southern African Malaria Control Programme, 2003).

2.2. Data

2.2.1. Malaria

Annual national malaria case data from 1988—1999 and corresponding population estimates were obtained from health information systems and/or annual malaria reports. This period was chosen because of the relative completeness of data from all the selected countries. The data consist of confirmed (Botswana, South Africa and Swaziland) and unconfirmed (Zambia) clinical cases as well as a combination of both (Zimbabwe).

2.2.2. ENSO

There is a varying list of indices that can be used to determine ENSO years. In this analysis we use annual averages of the Southern Oscillation Index (SOI), a measure based on the differences in the atmospheric pressure between Tahiti in the eastern equatorial Pacific and Darwin in Australia (West Pacific), expressed as a standard deviation from the norm and available from the National Oceanic and Atmospheric Administration website (http://www.cdc.noaa.gov/ClimateIndices/List/). SOI is used to quantify the strength of an ENSO event and is negative during El Niño (a warm event) and positive during La Niña (a cold event). In parts of Southern Africa, a strong El Niño event is usually followed by drought, and La Niña by flooding (Kovats, 2000; Kovats et al., 2003; Nicholls, 1993; Richard et al., 2000, 2001).

2.3. Analysis

To display the connection between annual averages of SOI and malaria incidence (per 1000 person-years) in the selected countries, annual standardised incidence anomalies (*SIA*) were calculated using the formula $SIA = (Y - \overline{Y})/\sigma$, where Y denotes the observed incidence in each year, $\overline{Y}$ the long-term mean and σ the standard deviation of Y. Scatter plots were used to examine the nature of the relationship between annual averages of SOI and log-transformed annual malaria incidence in each country. A negative binomial regression model with year-specific random effect was used to assess the association between SOI and annual malaria incidence. This model adjusts for overdispersion that may be present in the count data (malaria case data) and used random effects as surrogates for unmeasured factors influencing annual incidence. The analysis was performed in STATA version 9 (Stata Corp., College Station, TX, USA).

3. Results

Below normal annual incidence rates of malaria synchronised with negative SOI values (El Niño), i.e. dry conditions, and above normal incidence with positive SOI values (La Niña), i.e. wet conditions (Figure 1). During the study period, the SOI varied from −2.02 to 1.22, with a mean of −0.54 and SD of 1.28. Table 1 gives summary statistics of malaria incidence for the selected countries.

The SOI showed a positive relationship with annual malaria incidence in Botswana, South Africa, Swaziland and Zimbabwe, but not in Zambia. The negative binomial model

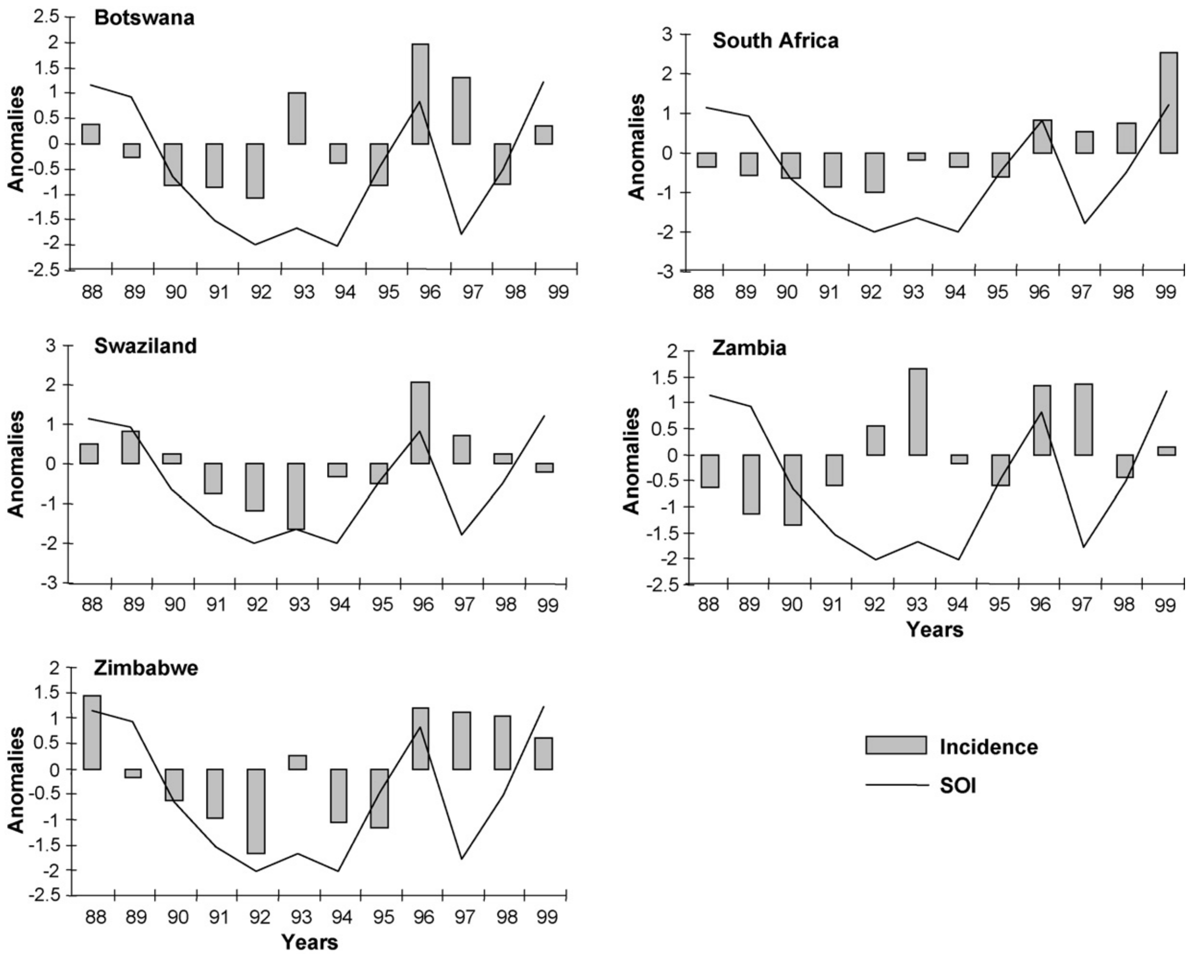

Figure 1 Standardised annual malaria incidence and Southern Oscillation Index (SOI) anomalies from selected countries in Southern Africa by year between 1988 and 1999.

(Table 2) confirmed that SOI increases annual malaria incidence in most of the selected countries, although by a small amount in Zimbabwe, and reduces incidence in Zambia although very slightly. However, these associations were statistically significant only in South Africa and Swaziland.

4. Discussion

The study period featured a very active ENSO cycle (Kovats, 2000; Kovats et al., 2003) and therefore offered an ideal opportunity for evaluation of the relative impact of this phenomenon on malaria incidence in the region. This includes the two major El Niño episodes recorded in 1991—1994 and 1997—1998 and two La Niña episodes in 1995—1996 and 1999. In general, malaria incidence anomalies appeared to be synchronised both with El Niño and La Niña events as described by SOI (Figure 1). Basically, ENSO events cause rainfall patterns to change and this usually affects mosquito breeding, which, in turn, is associated with variation in malaria transmission. However, the impact on malaria incidence may be complicated by non-ENSO factors such as insecticide and drug resistance or failure of malaria control programmes. Hence we used year-specific random effects as surrogates for unmeasured factors influencing annual malaria incidence.

Table 1 Estimated population in malarious areas and incidence in selected countries in Southern Africa from 1988—1999

Country	Population	Incidence (cases per 1000 person-years)			
		Mean	SD	Minimum	Maximum
Botswana	620 400	5.585	4.906	0.306	15.274
South Africa	4 429 500	0.363	0.307	0.060	1.139
Swaziland	279 300	6.295	3.370	0.716	13.318
Zambia	8 690 000	323.608	56.248	247.300	415.500
Zimbabwe	5 962 000	10.721	3.636	5.132	15.527

Table 2 Changes in annual malaria incidence (cases per 1000 person-years) associated with one unit increase in the Southern Oscillation Index in selected countries in Southern Africa

Country	IRR	95% CI	*P*-value
Botswana	1.548	0.720–3.330	0.263
South Africa	1.351	0.976–1.870	0.070
Swaziland	1.283	0.991–1.660	0.058
Zambia	0.968	0.895–1.046	0.409
Zimbabwe	1.073	0.902–1.276	0.426

IRR: incidence rate ratio estimated from negative binomial model.

In East Africa, ENSO events and in particular El Niño have been linked to changes in optimum climatic conditions (i.e. lead to above normal temperature and/or rainfall) and associated increase in epidemic risk (Kilian et al., 1999; Lindblade et al., 1999; Lindsay et al., 2000; Loevinsohn, 1994; Wort et al., 2004). In agreement with others (Kovats, 2000; Kovats et al., 2003; Nicholls, 1993), we found that in most of Southern Africa, ENSO as measured by SOI has the opposite effect during El Niño (dry) conditions and that heightened incidence coincides with La Niña (wet) conditions. A recent study in Botswana (Thomson et al., 2005, 2006) demonstrated the predictive value of the association between sea surface temperature, another ENSO index, and rainfall after removing the impact of non-climatic trends and a major policy intervention.

In most of the region, the positive relationship between SOI and annual malaria incidence probably reflects the effect of ENSO on the mosquito vector *Anopheles arabiensis*, which breeds in temporary rain pools and is therefore highly sensitive to fluctuations in weather conditions. In Zambia, the lack of an apparent association of SOI with malaria incidence may be due to the lack of effective malaria control and therefore the presence of *A. funestus*. This vector breeds in permanent swamps and streams that are less dependent on rainfall and therefore less affected by ENSO events. Historical records show that *A. funestus* was responsible for most of the malaria transmission in Southern Africa before the advent of DDT (De Meillon, 1947; Leeson, 1931), resulting in endemic malaria transmission even through the dry winter months. Where effective vector control by indoor residual spraying with DDT was implemented, *A. funestus* disappeared and *A. arabiensis* took over (Mabaso et al., 2004), maintaining levels of transmission that are highly susceptible to rainfall fluctuations. A further reason why malaria cases in Zambia do not appear to correlate with ENSO may be poorer data quality owing to routine inclusion of unconfirmed cases in the official statistics, and this is not accounted for in our models.

South Africa and her closest neighbour Swaziland have the most reliable data and showed the strongest associations of epidemics with ENSO, but the picture there may also be compounded by other oceanic systems such as the Quasi-Biennial and Quasi-Periodic Oscillations in the Indian Ocean, which have a moderating effect on the impact of ENSO (i.e. cause rainfall during El Niño) (Richard et al., 2000, 2001).

There were inconsistencies in the association between ENSO and malaria incidence in Botswana and Zambia in 1993 and in all the countries in 1997, possibly reflecting heterogeneity in the climatic effects of ENSO (Kovats, 2000; Lindsay et al., 2000). The impact also varies over time within countries depending on existing malaria control efforts and response capacity (Gagnon et al., 2002; Worrall et al., 2004). For example, the 1995–1996 epidemic subsided in most countries following the 1997–1998 El Niño episode, except in South Africa and Zimbabwe (Figure 1). In South Africa, the persistence of the epidemic was due to problems of insecticide and drug resistance (Bredenkamp et al., 2001; Hargreaves et al., 2000), and the severity of the epidemics was exacerbated when coupled with the La Niña in 1999. In Zimbabwe, socioeconomic problems were also beginning to compromise the malaria control programme (DaSilva et al., 2004; Kiszewski and Teklehaimanot, 2004).

ENSO-induced epidemics are responsive to control where effective antimalarial measures exist, but often not before causing considerable suffering and death (Kiszewski and Teklehaimanot, 2004; Worrall et al., 2004), and understanding the connection between ENSO-related climate anomalies and malaria is important for developing forecasting models to make it possible to plan for this. However, ENSO-based climate forecasting models still have to rely on case surveillance for early detection of higher than normal malaria incidence. This surveillance is also influenced by non-ENSO factors that should not be dismissed as random error or ignored. Thus, there is a need for quantitative studies that at the same time consider both ENSO-driven climate anomalies and non-ENSO factors influencing epidemic risk potential.

Conflicts of interest statement
The authors have no conflicts of interest concerning the work reported in this paper.

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